3.2.7. Radiative Effects of an Earlier Spring Snowmelt in Northern Alaska

Regional climate models fail to adequately simulate the complicated feedbacks that are peculiar to the Arctic. Empirical analyses of data from BRW and other Alaska North Slope sites provide a better physical understanding of climate change in this region. In particular, data from BRW reveal important factors that determine the annual cycle of snow cover there and the radiative perturbations caused by variations in surface albedo. What modelers refer to as a "temperature-albedo feedback" is evaluated in response to an advance in the date when the snow melts in spring on the North Slope. The timing of snowmelt is found to have a significant influence on the net surface radiation budget (NSRB) and temperature regime there.

Trend analyses of climate records from several northern Alaskan sites show variations on seasonal to decadal time scales. Time series have been correlated with synoptic-scale atmospheric circulation patterns to understand the interaction of dynamical and radiative processes. *Dutton and Endres* [1991] and *CMDL Summary Report No. 25* [*Schnell et al.*, 2001; pp. 65-67] give a historical overview of CMDL's monitoring of snowmelt at BRW. The detection and attribution of climate change in the vicinity of BRW are discussed in several published papers [e.g., *Stone*, 1997, 2001; *Lawrimore et al.*, 2001; *Stone et al.*, 2001, 2002]. Only the main results are summarized here.

A trend toward an earlier disappearance of snow in spring (i.e., melt date) in northern Alaska has been documented. Correlated variations in the timing of snowmelt are revealed in several independent records. Since the mid-1960s the spring melt has advanced by about 8.0 (±4.0) days over a significant region of northern Alaska, as shown in Figure 3.28. Earlier spring snowmelt is, in part, the consequence of decreased snowfall in winter, followed by warmer, cloudier spring conditions [e.g., *Stone et al.*, 2002].

In turn, changes in snowfall, temperature, and cloudiness are attributed to variations, or shifts, in regional circulation patterns, as is illustrated in Figure **3.29**. Back-trajectories [*Harris and Kahl*, 1994] were used in the analyses. For example, snowfall, measured in units of water equivalent precipitation (WEPC), is reduced when the advection of relatively warm, moist air from the north Pacific Ocean is blocked by a high-pressure system centered northwest of BRW during winter (Figure 3.29b versus 3.29a). Warm spring conditions prevail if there is more frequent flow from the south, as indicated in Figures 3.29d and 3.29f versus 3.29c and 3.29e. The combination would result in an earlier melting of the snow pack during May-June.

One consequence of an earlier melt is the increase in the NSRB that tends to warm the near-surface air through an albedo feedback. Table 3.10 contrasts the NSRB and temperatures for 3 early versus 3 late years of snowmelt at BRW. An early melt enhances the gain of radiant energy at the surface, warming the air in turn. In this case, a 2-wk advance in the melt date in June increases the NSRB by 25%, with an associated rise in temperature of about 1°. After an early melt, slight warming persists through August on average.

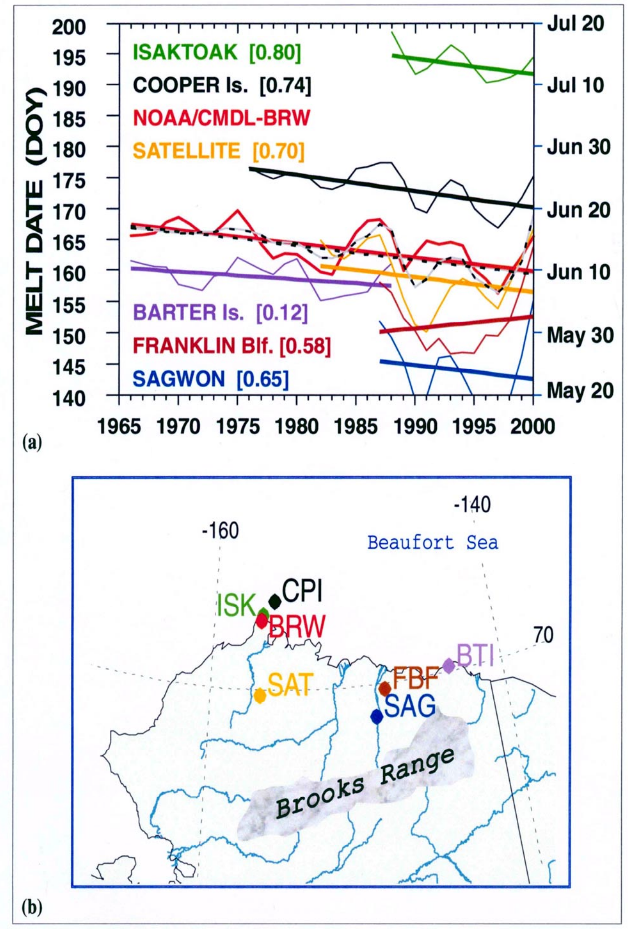

Fig. 3.28. (a) Analyses of six independent time series of measured or proxy melt dates (day of year) compared with the 1966-2000 CMDL BRW record (in red). Five-year smoothed time series and linear fits are shown. Each is cross correlated with the BRW record with coefficients indicated in brackets for individual sites that are labeled and color-coded. The dashed analysis (unlabeled) is for an ensemble average of the 142 station-years, normalized to the BRW timeframe. (b) Map of Alaska's North Slope showing the location of sites making up the ensemble [from *Stone et al.,* 2002].

This last result supports theoretical predictions of a positive feedback due to diminished snow and ice cover in the Arctic as a result of global warming. This temperature-albedo feedback is expected to enhance warming over the northern high latitudes [e.g., *Serreze et al.*, 2000]. The CMDL BRW observations are found to be representative of northern Alaska and establish baseline conditions for evaluating future climate change in this sensitive region of the Arctic. Also, the time series will be useful for verifying regional climate model simulations and for validating remote sensing algorithms being developed to monitor surface temperature and albedo needed to estimate the surface radiation balance [*Key et al.*, 1997]. Continued

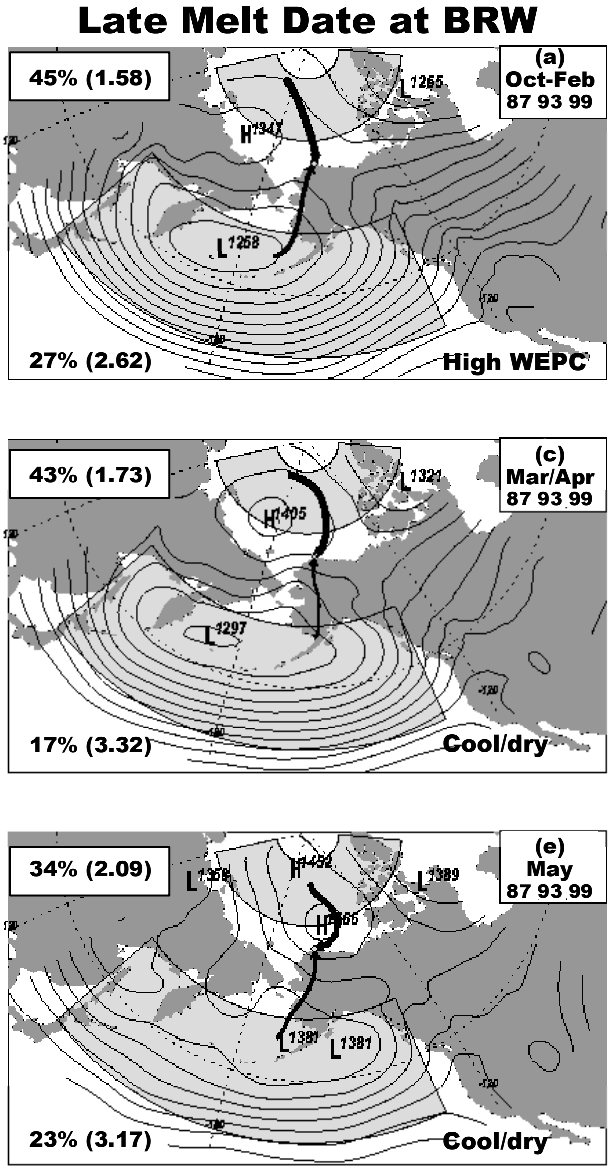

Fig. 3.29. Averaged, 1500-m back trajectories relative to BRW and corresponding 850-hPa geopotential height fields for (a) October-February 1987, 1993, and 1999, (b) October-February 1990, 1996, and 1998, (c) March-April 1987, 1993, and 1999, (d) March-April 1990, 1996, and 1998, (e) May 1987, 1993, and 1999, and (f) May 1990, 1996, and 1998, showing the multiyear, seasonal average, 5-day air flow from source regions indicated as lightly shaded areas. The percent frequency of transport and average transit time from each source region (in days) are indicated in the legends. In each panel the upper left legend relates to flow from the Arctic source region, and the lower left legend relates to flow from the North Pacific source region. The thickness of trajectories is proportional to their frequency and their lengths inversely proportional to average speed along track. These average trajectories represent the mean flow of all individual trajectories from the respective regions over each period indicated in the upper right-hand legend. The late melt dates at BRW were due to higher October-February snowfall (measured as water equivalent precipitation (WEPC)), followed by cool/dry spring weather conditions, compared with early melt date years. A more detailed explanation is given by *Stone et al.* [2002].

TABLE 3.10. Comparison of Net Surface Radiation Budget and 2-m Air Temperatures for Late Versus Early Years of Snowmelt at BRW

Years Sampled	Late Melt Date (1992, 1999, 2000)	Early Melt Date (1990, 1996, 1998)
Melt date (DOY)	164 (0.8)	150 (0.8)
NSRB (MJ m^{-2})		
June	306 (2)	385 (7)
May-August	860 (17)	970 (43)
T_{2m} (°C)		
June	0.9 (0.59)	1.8 (0.36)
July-August	3.3 (0.62)	3.6 (0.87)

DOY, day of year; NSRB, net surface radiation budget (in units of total radiative energy); T_{2m}, air temperature at 2 m above ground level.

Standard deviations are given in parentheses.

monitoring of the snow cycle at BRW and the factors that determine it is essential. The timing of the spring melt on a pan-Arctic scale will influence not only the regional energy budget (temperature regime) but also biogeochemical cycles that affect the sources and sinks of methane and carbon dioxide, imposing other potential climate effects [e.g., *Oechel et al.*, 1995; *Myneni et al.*, 1997]. Already, the changing Arctic climate is affecting indigenous people who depend on fishing and hunting grounds that are being modified [*Morrison et al.*, 2001].